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Development of a

Production Ready Automated

Wire Delivery System

Final Report

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List of Acronyms/Abbreviations

A/D	ANALOG TO DIGITAL
ASOC	AUTOMATIC STANDOFF CONTROL
AVC	AUTOMATIC VOLTAGE CONTROL
AWDS	AUTOMATED WIRE DELIVERY SYSTEM
COTS	COMMERCIAL OFF-THE-SHELF
CPU	CENTRAL PROCESSING UNIT
DC	DIRECT CURRENT
EEROM	ELECTRICALLY ERASABLE READ ONLY MEMORY
GTAW	GAS TUNGSTEN ARC WELDING
IPS	INCHES PER SECOND
MAWSAWC	MARSHALL ADVANCED WELD SYSTEM
MSFC	MARSHALL SPACE FLIGHT CENTER
MWG	MOTORIZED WIRE GUIDE
NASA	NATIONAL AERONAUTIC and SPACE ADMINISTRATION
NRC	NICHOLS RESEARCH CORPORATION
PAL	PROGRAMMABLE ARRAY LOGIC
PC-AT	PERSONAL COMPUTER - AT
PID	PROPORTIONAL INTEGRAL DERIVATIVE
PWM	PULSE WIDTH MODULATION
RAM	RANDOM ACCESS MEMORY
R&D	RESEARCH AND DEVELOPMENT
SBIR	SMALL BUSINESS INNOVATIVE RESEARCH
VPPAW	VARIABLE POLARITY PLASMA ARC WELDING

SECTION 1. EXECUTIVE SUMMARY

NASA has had a strong interest in automating the variable polarity plasma arc welding (VPPAW) process used for space shuttle external tank fabrication for many years, REFERENCES 1-3. One important part of the VPPAW process is the correct placement of filler wire. Robotic applications using the VPPAW process (such as that planned for the space station berthing port) will make it difficult, if not impossible, for the operator to monitor and provide the fine adjustments to the placement of filler wire needed to assure a quality weldment. The complexity and size of the berthing port restricts the operator's access to weld area, preventing direct observation of the weld. Safety guidelines may also prevent the operator from entering the robotic working envelope while it is in operation. Filler wire placement automation is the solution to these problems.

The objectives of this Phase III contract were: production harden the existing Automated Wire Delivery System (AWDS) motion and sensor hardware; develop a single board VME bus controller for the AWDS; test the redesigned AWDS in a range of welding applications. The result of this contract was an AWDS that was transitioned from the laboratory environment to the production environment. The contract was later amended to include the integration of the VME based controller AWDS into the Marshall Weld System Advanced Weld Controller (MWSAWC).

The development program was divided into two development tasks to meet the program objectives. The first task redesigned the motorized wire guide (MWG) including the wire guide tip. The second task developed the VME bus based AWDS controller. Testing was performed after the two development tasks were completed. A third task, integration into the MWSAWC, was to be performed after the completion of the first two tasks.

Task I, production harden the MWG, began with a review of the prototype MWG. From this review, a set of design goals were established for the production hardened MWG. These design goals were: minimize the overall size; improve the motor drive design to resolve speed and binding problems; generate engineering drawings; improve the wire guide tip cooling; provide crash protection; improve the motor/drive coupling; improve the liner attachment; reduce the ball-joint-rod-end play; improve the final packaging aesthetics.

A new drive mechanism for the MWG was designed and a prototype of a single motor drive assembly was manufactured and evaluated. A new wire guide tip assembly was designed. A design review was held at NASA where the new MWG design was presented. The design changes were accepted as proposed. The production MWG design was finalized and a complete set of mechanical drawings was generated for a three-axis MWG drive assembly and wire guide tip. The production hardened MWG was manufactured and assembled at Nichols Research Corporation (NRC). The production MWG was integrated with the prototype STD bus AWDS controller. The production MWG was installed on a robotic welding system and its operation verified.

The Task II development of a VME bus based AWDS controller began with the requirements definition for the production AWDS. A design requirement was that the VME bus controller board function as either a stand-alone AWDS controller or a VME bus based AWDS controller. The stand-alone AWDS consists of an operator's terminal, a joystick control interface, the production MWG assembly, cables and the stand-alone controller assembly. A hand held terminal was selected to provide a good operator's interface that was both robust and easy to use. The joystick interface allows users to integrate the motion controls of the AWDS into their own pendant or onto a switch-based joystick control. The stand-alone controller assembly contains the VME bus controller board, a three axis motor driver/amplifier, power supplies, wiring and cabling. The stand-alone system was developed to provide a simple platform to design and test the control software and integrate all of the system components.

The initial system design task defined how the system would operate, which operator controls would be provided, which parameters needed to be operator programmable, how the operators terminal would operate, which different modes would be provided, how the different control interfaces, the terminal, joystick and VME bus, would interact, etc. The hardware and software design tasks defined the hardware interfaces, which processor would be used, how the VME bus interface would operate, which sensor interface would be provided, the connector and pin-outs of the VME bus controller board interfaces, how much memory was needed, how the system configuration information is stored, etc. With these decisions made, work on the hardware and software began in parallel. The operational software and the operator's terminal software was developed using the existing STD bus based prototype AWDS control system in parallel with the VME bus controller board design. After the VME bus controller hardware was manufactured and tested, software development was completed on the new VME bus controller stand-alone system. The stand-alone system was operationally tested at NASA with different configurations and weld procedures using different wire sizes and welding processes. The VME bus control functions were tested in an embedded VME bus control system.

The Task III, integration of the VME based AWDS controller with the MWSAWC as an embedded controller, began with a review of the existing weld controller design to determine how closely coupled the AWDS could be integrated without impacting the existing software. NRC with the assistance of Lockheed Martin Corporation personnel developed a three-phase integration effort

SECTION 2. INTRODUCTION AND BACKGROUND

2.1 *INTRODUCTION*

The current development effort is a Phase III research study entitled "A Production Ready Automated Wire Delivery System", contract number NAS8-39933, awarded to Nichols Research Corporation (NRC). The goals of this research study were to production harden the existing Automated Wire Delivery (AWDS) motion and sensor hardware and test the modified AWDS in a range of welding applications. In addition, the prototype AWDS controller would be moved to the VME bus platform by designing, fabricating and testing a single board VME bus AWDS controller. This effort was to provide an AWDS that could transition from the laboratory environment to production operations.

The project was performed in two development steps. Step I modified and tested an improved MWG. Step II developed and tested the AWDS single board VME bus controller. Step III installed the Wire Pilot in a Weld Controller with the imbedded VME bus controller.

2.2 *DEVELOPMENT HISTORY*

This development project began in 1988 as an SBIR Phase I research study entitled "An Investigation Into The Feasibility Of Automating The Filler Wire Placement For Robotic Welding Applications", contract number NAS8-38024, awarded to General Digital Industries, Inc. The overall objective of the Phase I research program was to explore the feasibility of completely automating the wire feed system, thus bypassing the need for operator access to the point of welding. This included an analysis of the requirements, a description of the functional aspects, an evaluation of the feasibility, and development of a phase II plan. In the initial research effort, the requirements for a wire delivery system to assure a quality weldment was investigated. Various forms of sensing technologies were evaluated for their ability to provide information related to the delivery of wire into the weld pool. These were; torque on the wire feed motor, resistance between the wire and work piece, plate contour and torch to work distance. The types of software necessary for automatic wire delivery were also described.

Results of the Phase I study described new techniques and procedures required for maintaining the delivery of filler wire into the weld pool for robotic VPPAW and GTAW welding applications. Several approaches for automating the wire delivery system were suggested. It was recommended that a to breakdown the involvement of the individual parties needed to fully integrate the capabilities of the Automated Wire Delivery System. Step 1 is performed as part of this development contract.

Step 1 of the integration process integrates the AWDS hardware into the weld controller cabinet, installs the motorized wire guide on the weld head and uses the AWDS pendant as the stand-alone operator controls. There are no software connections between the AWDS controller and the MWSAWC controller. The AWDS operates independently and autonomously. Software drivers are developed for future integration efforts and a simple software monitoring routine is developed to validate the software driver functionality.

Step 2 of the integration process provides a partial MWSAWC pendant integration. A user interface screen would be developed for AWDS configuration, displaying errors, controlling the start and stop of automatic operation and for displaying real-time position and status information. Lockheed Martin Corporation Personnel would perform this part of the integration.

Step 3 of the integration process integrates the AWDS operation into the weld schedules and real-time control by the weld control software. This project would require an additional subcontract with HOBART to perform this integration task. The results would be the total integration of the AWDS.

Step 1 of task III was performed on the Vertical Tool located in building 4705. Cables, drive components, pendant and mounting hardware were secured for the integration effort. The AWDS Controller and motor dive components were installed in the weld control cabinet. The motorized wire guide was installed on the tool above the torch. The system components were installed and tested. NRC developed software drivers, allowing the development of software by the user to monitor the operation of the Wire Pilot. The user developed a software program to monitor and display the operational status of the AWDS. Control of the motorized wire guide is performed by the weld operator with the use of the hand held pendant provided with the system. Additional integration of the AWDS requires further software development by the user.

This development program has produced an AWDS, renamed the WIRE PILOT, capable of maintaining the proper filler wire position during welding for both robotic and non-robotic VPPAW and gas tungsten arc welding (GTAW). The redesigned system greatly improves the operational capabilities, precision and adaptability of the previous design. The WIRE PILOT is ready for the production environment.

prototype system be developed to demonstrate the worth and plausibility of automating the wire delivery system for each of the robotic VPPAW and GTAW applications.

The research continued in a Phase II SBIR contract, a research study entitled "Development of an Automated Wire Delivery System for Robotic Welding Applications", contract number NAS8-38477 awarded to NRC. Four areas of research were tasked in this R&D contract: wire feed system development; sensor system development; motion system development; control system development. These four research tasks were the basis for specifying the requirements for a prototype AWDS.

The Phase II SBIR resulted in the delivery of a prototype AWDS consisting of a STD bus based control system with a two-axis MWG and a three-axis MWG. Both used a pressure sensor and a wire contact sensor to provide feedback on the wire placement. The pressure sensor located in the wire guide tip allowed the AWDS control system to maintain the wire in contact with the work, constantly reacting to AVC changes and material thickness changes. NASA patented this concept; patent number 5,302,805 dated April 12, 1994. The prototype equipment was delivered to NASA and installed on a robot welding system. The operator controlled the placement of the wire using a three-axis joystick control. Based on the results of this development effort, NRC recommended the prototype wire delivery system be developed into a production product by fabricating an improved, smaller motorized wire guide and developing a single board AWDS VME bus Controller.

SECTION 3. DEVELOPMENT PROGRAM

The Production Ready AWDS development program was implemented with two development tasks. Task I redesigned the MWG. Task II moved the controller design to the VME bus platform.

3.1 PHASE I - MWG REDESIGN

The Task I contractual goals were to modify the current MWG design, fabricate a new MWG, test the redesigned MWG and evaluate the overall effectiveness and sensitivity of the AWDS on a large variety of welding applications. Modifications were to be provided to the wire pressure control algorithm as needed for effective operation with different welding processes, orientations, filler materials and base materials.

The redesign of the MWG was preceded by an analysis and review of the Phase II design. NRC interviewed the operators of the prototype equipment. A list was compiled of problems identified with the MWG hardware and changes requested in the AWDS operation. The problems and change requests are listed in table 1 below.

Table 1. Prototype MWG Problems and Change Requests

1. Drive screws damaged when the MWG crashed into work.
2. Wire Path through the tip is non-linear. (Caused by MWG crashing into the work).
3. Lead screws bind causing the motors to stall.
4. There is no cover for the MWG. It looks unfinished.
5. The wire guide tip is floppy. The tip front was retained with a wire tie)
6. The MWG jog speeds are too fast and not easy to modify.
7. Cross-seam motion should be linear.

A list of design goals for a production MWG was generated from the problem analysis and the statement of work, see table 2 below.

Table 2. Design Goals for a production MWG

1. Redesign wire guide tip body to provide sufficient heat dissipation during welding.
2. Replace current screw/tip mount O-rings with anti-backlash mechanism and enhance machining procedures to produce tighter tolerance rotating components.
3. Redesign the wire guide packaging to improve miniaturization.
4. Increase the strength of the extension arms.
5. Improve appearance of equipment.
6. Provide crash protection.
7. Reduce wire guide tip play.
8. Improve the motor drive design to prevent binding of the lead screws.
9. Improve drive screw to wire guide tip mounting design (ball-joint rod-end play reduction).
10. Increase the speed of MWG.
11. Improve motor coupling to the driven shaft.
12. Coordinate motor movement to provide linear cross-slide motion.
13. Coordinate motor movement when changing angles, so the filler wire always points to a fixed point.
14. Home switches to locate the drive screws within +/- 0.010 inches repeatedly.

A preliminary single motor drive design was developed. A prototype production single motor drive assembly was manufactured and tested. A preliminary design of a three-axis production hardened MWG was developed based on the single motor drive design. A list of pros and cons was generated for the proposed three axis production MWG (see table 3).

Table 3. MWG Redesign Pros and Cons

Old Design	New Design	Pros	Cons
Basic housing unit 1.25" square	Basic housing unit 1" square	Reduces height and width	None
Three separate motor housings - two motor housings hinged	One monolithic three axis motor housing - Spring coupler added	Reduces play at housing pivot - Reduce play at rod ends	Adds 1" in overall length
Motor directly connected to drive nut	Motor connected to drive by flexible coupler	Less stringent hole alignment requirements - easier to machine	Adds 1" in overall length
Motor turns nut that drives lead screw. Lead screws could be driven out of the MWG	Motor turns lead screw which drives nut	More efficient design - cannot physically drive extension arms out of housing	None
Extension arms are 0.25 inch diameter lead screws	Extension arms are 1/2" diameter Stainless Steel rod	Better bearing surfaces. Tighter tolerances / reduced play. More strength. Lead screw not exposed to dirt and contamination	None
Tip Housing is 1 inch wide (not including ball joint connections)	Tip housing 0.67" wide with chamfered edges	Less intrusive to reach into deep grooves or deep tooling.	None
Ball ends rotate when moving, causing tip position changes	Anti-rotation block on drives prevents rotation of the extension arms	Extension arms don't rotate, reducing backlash	Adds 0.75" to length. Requires tight tolerance machining
Three housings mounted on two plates	Monolithic motor housing	Precision alignment of motor drives	Requires tight tolerance machining
Utilized carbon steel extension arm / lead screw	Uses 303 stainless steel extension arms and lead screws	Material is rust resistant	Slight increase in cost
Electrical insulation at tip	Tip insulated at ball ends, extension arm bushings and anti-rotation block mounting	Insulation farther from heat source - won't need active cooling	Tip assembly electrically hot
Pulsed limit home position, hole drilled in nut and lead screw blocks hole	Flag blocks an optical sensor light beam	Simplifies homing software and increases home position accuracy	Extra complexity and slight increase in cost
Extension arms susceptible to impact damage	Stronger extension arms installed in an impact protected housing	Extension arms able to survive impact better.	Extra complexity and slight increase in cost
Extension arms susceptible to impact damage	Two levels of crash protection	Large impact will push tip, then entire MWG back 1"	Extra complexity and cost. 1/4" extra height

The new design was presented to NASA. With a positive response from the design review, production began on the three-axis MWG design. Engineering drawings were generated, the components were manufactured, and a three-axis unit was assembled.

There were very basic design changes made between the prototype MWG and the production hardened MWG. The basic design of the drive axis of the old MWG is shown in figure 1. It consisted of a single block of aluminum, machined to enclose a dc motor, a drive nut, a single bearing and a limit switch. A small diameter threaded rod was driven in or out when kept from rotating by its attachment to a wire guide tip. The production hardened motor drive for a single axis design is shown in figure 2. The motor is no longer encased in an aluminum block but attached to a motor mounting plate. The motor drives a lead screw instead of a nut. The output shaft is a ½ Inch stainless steel rod to increase strength. The lead screw and the hollow drive shaft are coupled with an anti-rotation block machined from G-10 fiberglass material. The ACME threaded drive nut is screwed into the anti-rotation block on one side and the drive shaft is screwed into the block from the opposite side. The anti-rotation block slides in a machined slot in the aluminum drive housing. A plastic bushing is installed at the end of the drive housing through which the drive shaft slides. The lead screw is installed in the housing and retained with E-ring and nylon spacers. The lead screw is connected to the drive motor with a bellows coupler.

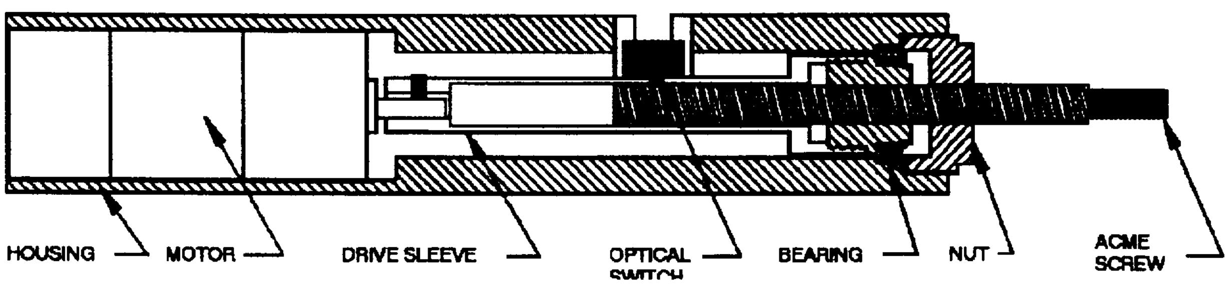

Figure 1. 1-Axis Prototype (Phase II) Motor Drive Assembly

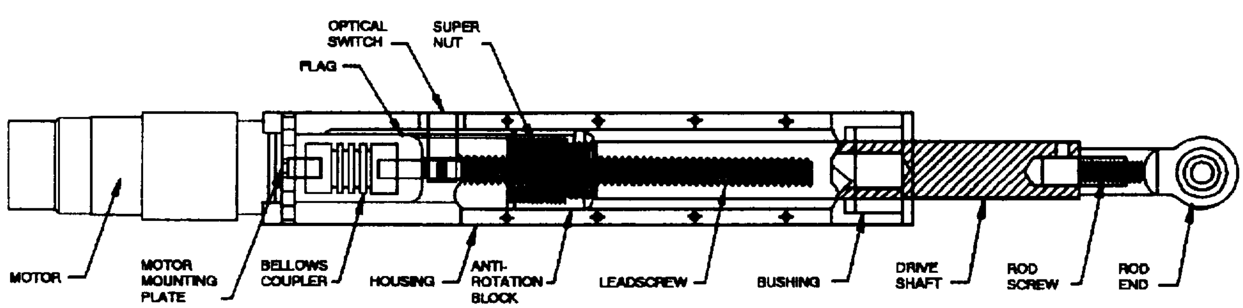

Figure 2. 1-Axis Production Ready (Phase III) Motor Drive Assembly

The prototype three-axis MWG assembly consisted of three individual motor block assemblies mounted on two plates. One motor block assembly was held rigid while the other two motor block assemblies moved, one rotating in the vertical plane and one rotating in the horizontal plane. This was necessary to allow for the movement of the attachment points to the wire guide tip when changing tip angle or cross-slide position. To reduce size, the production MWG consists of a monolithic housing in which three motor drive assemblies are installed. A spring is located at the end of the upper drive shaft to provide for the dimensional changes at the attachment points of the drive shafts to the wire guide tip when the MWG changes angles or cross-slide position. Figure 3 shows a photograph of the two and three axis prototype MWGs. Figure 4 shows a photograph of the production three axis MWG. The production three axis MWG is mounted on a slide plate assembly, sandwiching a linear slide and springs between two machined plates.

This assembly allows the whole three axis motor assembly to slide backwards 1" when excessive pressure (enough force to overcome the spring tension) is applied to the wire guide tip. Figure 5 shows a side view assembly drawing of the production three axis motorized wire guide.

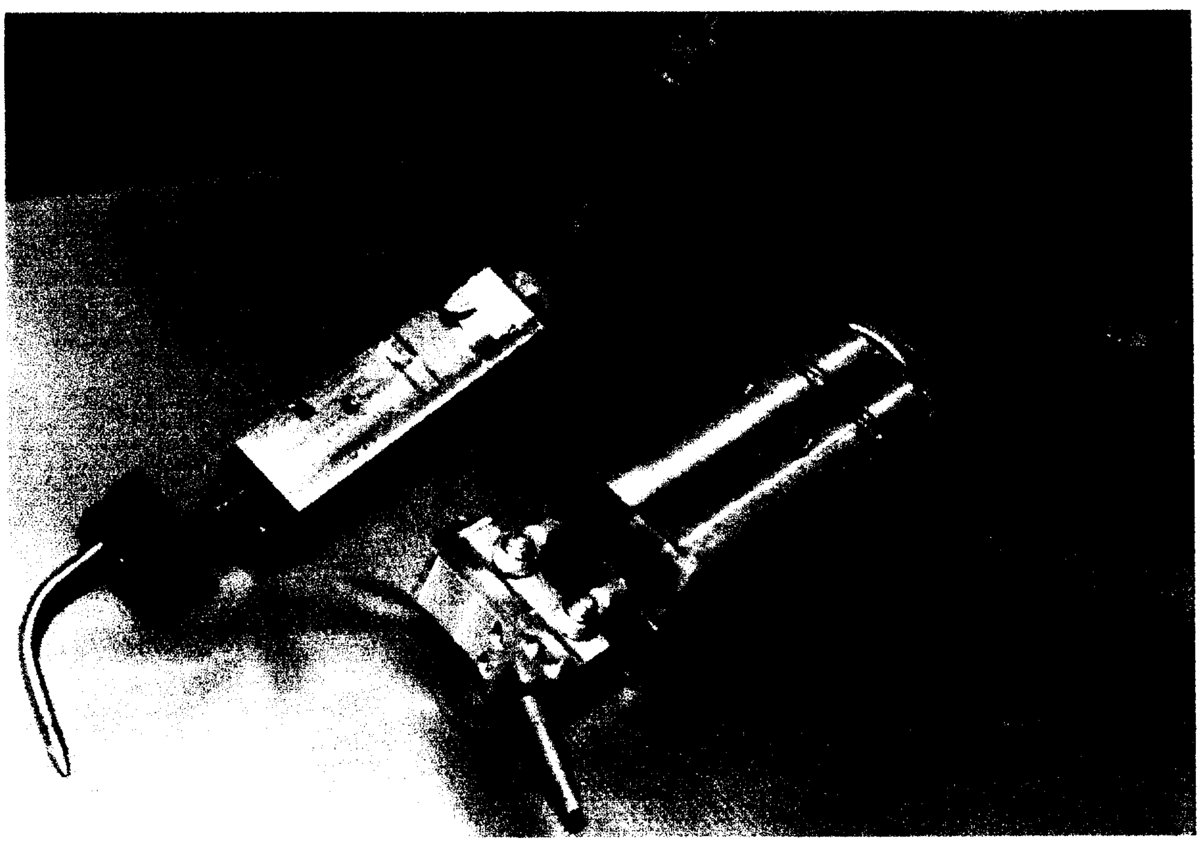

Figure 3. Photograph of Prototype MWG

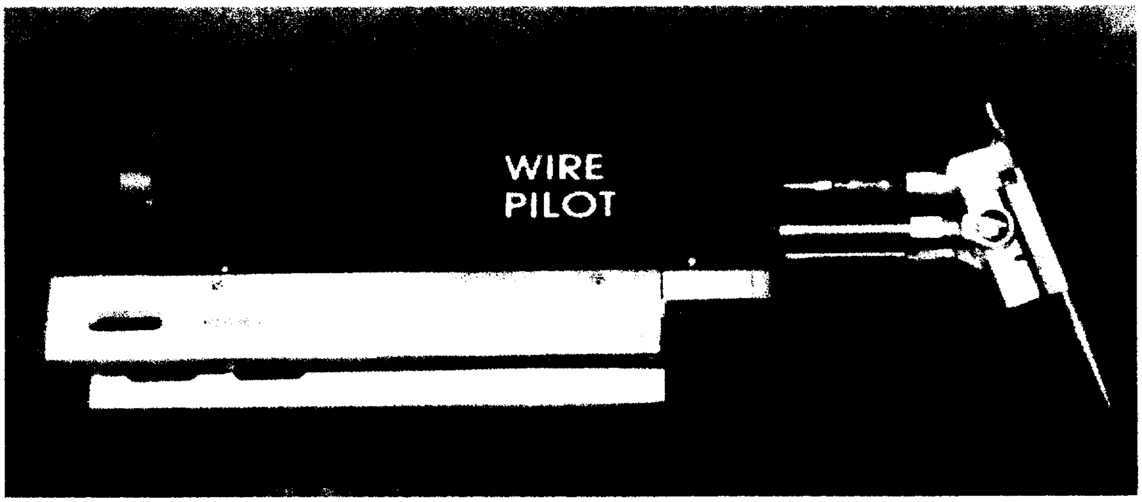

Figure 4. Photograph of the Production MWG

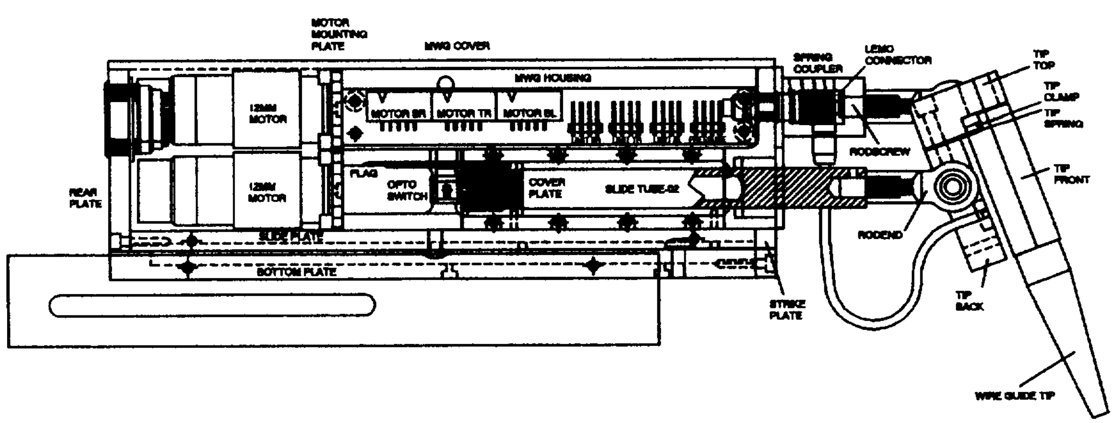

Figure 5. Production MWG Assembly Drawing

The prototype wire guide tip design had problems with heat dissipation, electrical isolation and rigidity of the tip front. It consisted of four machined aluminum pieces, one fiberglass insert and a spring, plus assembly hardware (see figure 6A). The tip front is connected to the tip back with a flat spring. Two screws limit the forward motion of the tip front as force is applied to the pressure sensor by a setscrew. The pressure sensor pre-load has to be very small because of hardware and software constraints, causing the tip to be floppy. The temperature and electrical isolation problems are coupled. The copper wire guide tip must be electrically isolated from the motor drive assembly.

The prototype design used an insert made of electrically non-conductive material. The material provides electrical isolation but not heat conduction for the copper tip. Also, the mechanism for holding the insert in position allows the insert to rotate, causing a misalignment in the wire path. The production wire guide tip design corrects all of these problems with the prototype design. It consists of four aluminum pieces, one flat spring and assembly hardware. The production tip design is shown in figure 6B. The production tip design uses the tip-top as the mechanical stop for the tip front when pre-loading the pressure sensor. The controller design allows a greater pre-load set point that enables the tip front to be held rigidly in place. The production tip design screws the copper tip directly into the aluminum tip front, providing a much larger heat sink and a good thermal conduction path. Electrical isolation at the copper tip connection is not necessary in the production design because electrical isolation is provided inside the motor drive assembly with the plastic bearings and the fiberglass anti-rotation block and plastic super nut. The production tip is much thinner but longer front to back than the prototype. This allows the tip to fit into tighter spaces then the prototype, such as when welding in a groove.

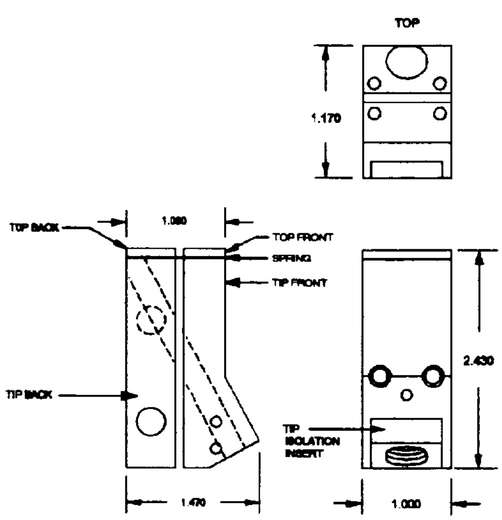

Figure 6A. Prototype Tip Design

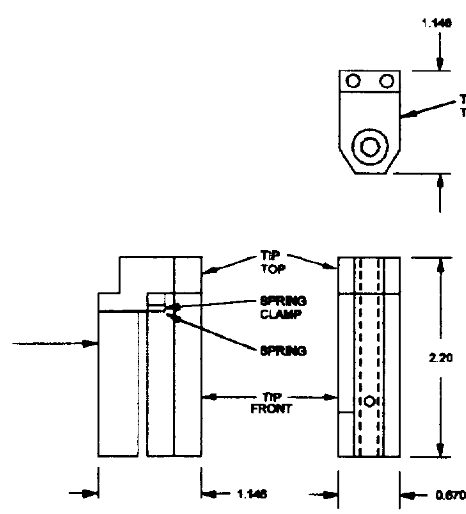

Figure 6B. Production Tip Design

The AWDS STD bus based controller was used to operate the new MWG. Initial testing verified that the new design met all of the design goals. It was installed, shown and operated on a robotic weld tool at NASA/MSFC (see figure 7). The STD bus based controller and MWG were removed to NRC and used to develop and test software design changes to the AWDS operation.

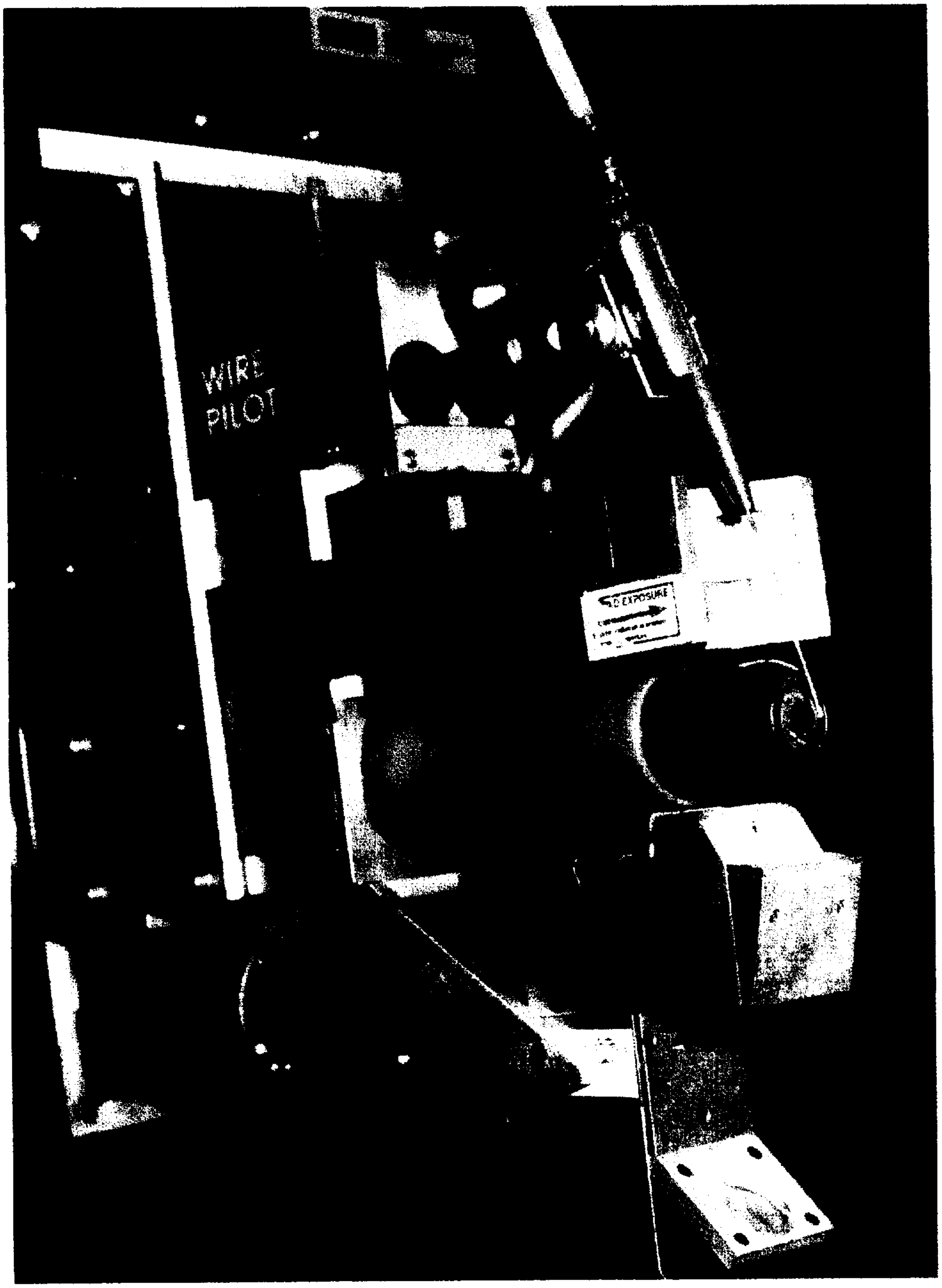

Figure 7. Photograph of production MWG installed on robotic tool

3.2 PHASE II - VME bus BASED CONTROLLER DEVELOPMENT

The phase II goal of this development program was to move the AWDS controller design from the STD bus to a single VME bu board. The VME bus controller board is being developed to be insta.led and operated in a VME bus based computerized weld control system. The new controller is designed to be installed in the backplane of the VME bus computer system. The AWDS functions would be controlled through the VME bus interface.

As system developers, a second goal was introduced for the AWDS VME bus controller: to operate as part of a stand-alone AWDS. This concept was desired to allow the VME bus controller board to be developed, tested and integrated with the other AWDS components without the need for a VME bus based weld control system.

A system block diagram of a system which meets these goals was developed (see figure 8). The new AWDS was named the WIRE PILOT. Since the control system is microprocessor based and the application could be varied, a way for changing and storing the operational characteristics of the system was required other than through the use of the VME bus interface. A hand held terminal was selected with enough functionality to be used to configure and operate a stand-alone WIRE PILOT system. A digital I/O interface was provided to allow an end user to integrate the motion control functions of the WIRE PILOT into a joystick control mechanism or their own switch controlled operator's pendant. The WIRE PILOT controller provides digital I/O circuitry that may be connected with the welding equipment emergency stop system. The WIRE PILOT controller had to provide all the necessary motor and position controls to operate the production MWG. A three-channel PWM motor amplifier board interfaces the motor speed and direction controls from the WIRE PILOT controller to the MWG motors. The WIRE PILOT controller requires both +5 volts and +12 volts to operate. The three-channel PWM motor amplifier board requires a separate isolated +15 volt power supply to power the motors.

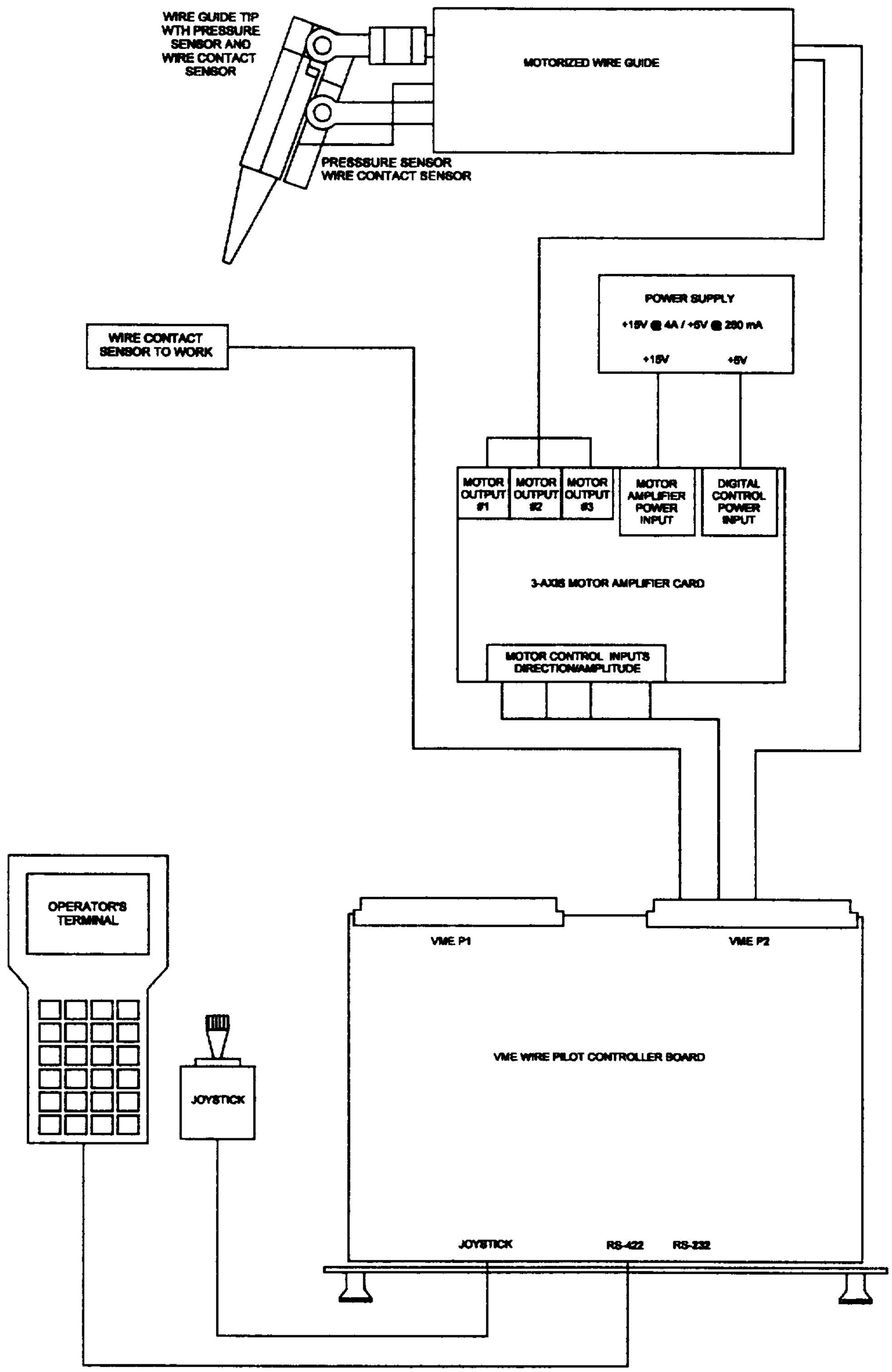

Figure 8. System Block Diagram

The next design step was to define how the system would be controlled and configured by the operator. Table 4 lists the modes of operation and commands available to the operator using the terminal or the computer using the VME bus interface. Other questions were discussed such as: how should the system react to operator commands; what joystick controls are needed; how much memory is needed; which processor should be selected; how should we implement the VME bus interface controls. System hardware and software design details took many weeks to define.

Table 4. Operational Modes and Commands

Idle Mode	Configuration Mode	Manual Mode	Auto Mode
Go Home	Load Config 1,2,3,4 or 9 (Factory Configuration)	Go Home	MWG Cross-slide right +X
Go To Config. Mode	Save Config 1,2,3 or 4	Store Home Position	MWG Cross-slide left -X
Go To Manual Mode	Wire Pressure Set Point	Go To Config Mode	MWG Tip Angle Up +Z
Calibrate Pressure	PID Gains: Proportional; Integral; Derivative	Go To Auto Mode	MWG Tip Angle Down -Z
	Increase Wire Pressure when dripping?	MWG Cross-slide right +	
	Amount Increase of Pressure when dripping	MWG Cross-slide left -X	
	Max Pressure on Auto Increase	MWG Tip Angle Up +Z	
	Wire Drip Time before Pressure Increase	MWG Tip Angle Down -Z	
	Axis Speed Manual: X IPS; Y IPS; Z deg/sec	MWG Tip Forward +Y	
	Axis Speed Auto: X IPS; Z deg/sec	MWG Tip Reverse -Y	
	Perform Home When Reset	Program Move 1	
	Home Position: X; Y; Z	Inverse of Program Move 1	
	Relative Move #1: X; Y; Z	Program Move 2	
	Relative Move #1: Enable Y/X ; Enable Y/Z	Inverse of Program Move 2	
	Relative Move #2: X; Y; Z	Calibrate Pressure	
	Relative Move #2: Enable Y/X; Enable Y/Z		
	Wire Guide to Torch Centerline distance		
	Pendant Screen Back-light Time-out		

The next design step was to determine the connector type and pin definitions of the WIRE PILOT controller board interfaces. The VME bus interface connects through a 96 position VME bus P1 connector. The MWG interface connections are provided on a 96 position VME bus P2 connector. The digital I/O (joystick) connections are provided through a 15 pin D-sub connector. The RS-422 serial interface to the operator's terminal is provided with A 9 pin D-sub connector. A second 9 position D-sub connector provides a simple RS-232 serial interface, which is used for software development and testing.

The next design step was to develop the VME bus controller board block diagram. The block diagram defines all the hardware functionality of the controller board. A schematic was created for each of the system blocks and the blocks were interconnected at the top level of the design. The design process developed circuitry to implement each of the block elements in the following order: the CPU block; the memory interface block; the serial interface block; the motor control bloc; the wire contact sensor block; the digital I/O block; the wire pressure sensor interface block; and the VME bus interface block. The VME bus controller board block diagram is shown in figure 9.

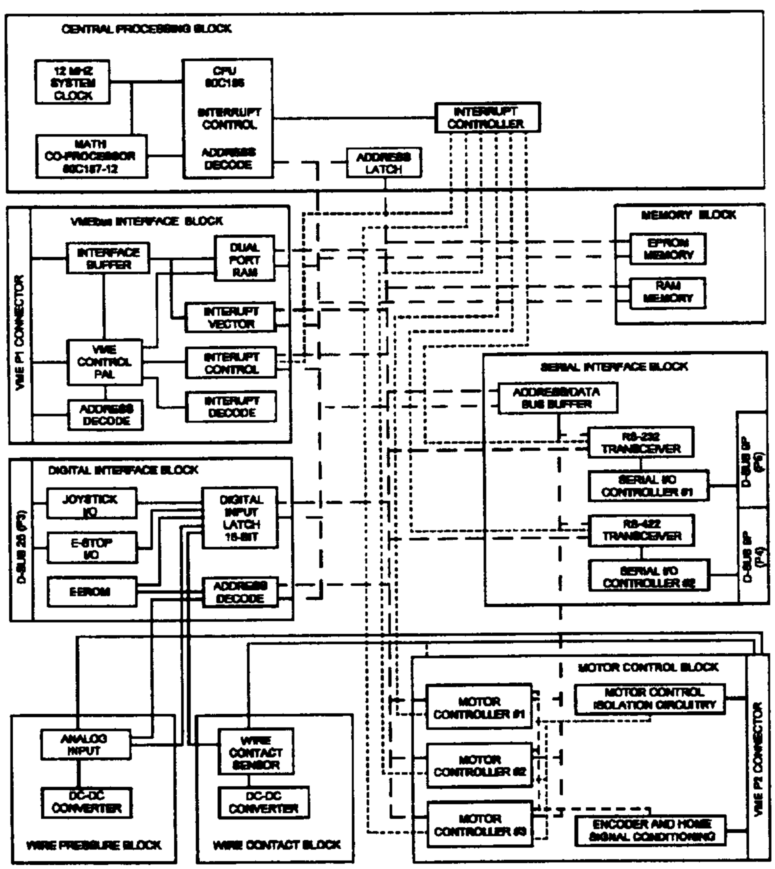

Figure 9. WIRE PILOT Controller Functional Block Diagram

The CPU block design consisted of the microprocessor, the math coprocessor, clock circuitry, "power on" reset circuitry, CPU interrupt circuitry, board addressing, and generation of the address and data bus. The memory block design consisted of both EPROM and RAM with jumper selection of different memory sizes. The serial interface block design consisted of interfacing two serial I/O controller chips, signal conditioning, connector and pin-outs for an RS-232 serial port and RS-422 serial port. The motor control block design consisted of interfacing three motor controller chips, signal conditioning for the encoder feedback, limit and home inputs, and signal isolation for the motor control signals, amplitude and direction. Connector pin definitions for the VME bus P2 connector were included in this block. The wire contact sensor block design consisted of the wire contact sensor circuit and a DC-to-DC converter power supply circuit providing electrical isolation of this circuit from the rest of the controller board circuitry. This circuit had to be isolated because of the weld voltages that may appear on the sensor input signals. The digital I/O block design consisted of I/O latches and address decoding circuitry. This block also included the signal conditioning for the joystick interface signals, E-Stop interface signals and the EEROM interface which is used for long term storage of the programmed configuration data. The wire pressure sensor block design consisted of an analog-to-digital and pressure sensor drive circuitry. A DC-to-DC converter in this block generates -5 volts needed by the A/D converter. The VME bus interface block design consisted of a shared memory interface, VME bus interface circuitry and VME bus interrupt control circuitry. A PAL device generates most of the control signals necessary for interfacing with the VME bus. Address comparators and jumper blocks allow the user to select the board address and interrupt level.

From the schematic, both a wire list and a parts list were generated. Parts were placed on order to build two systems. The wire list was used to produce a PC board layout and art work from which two prototype PC boards were manufactured. Figure 10 shows the controller board layout.

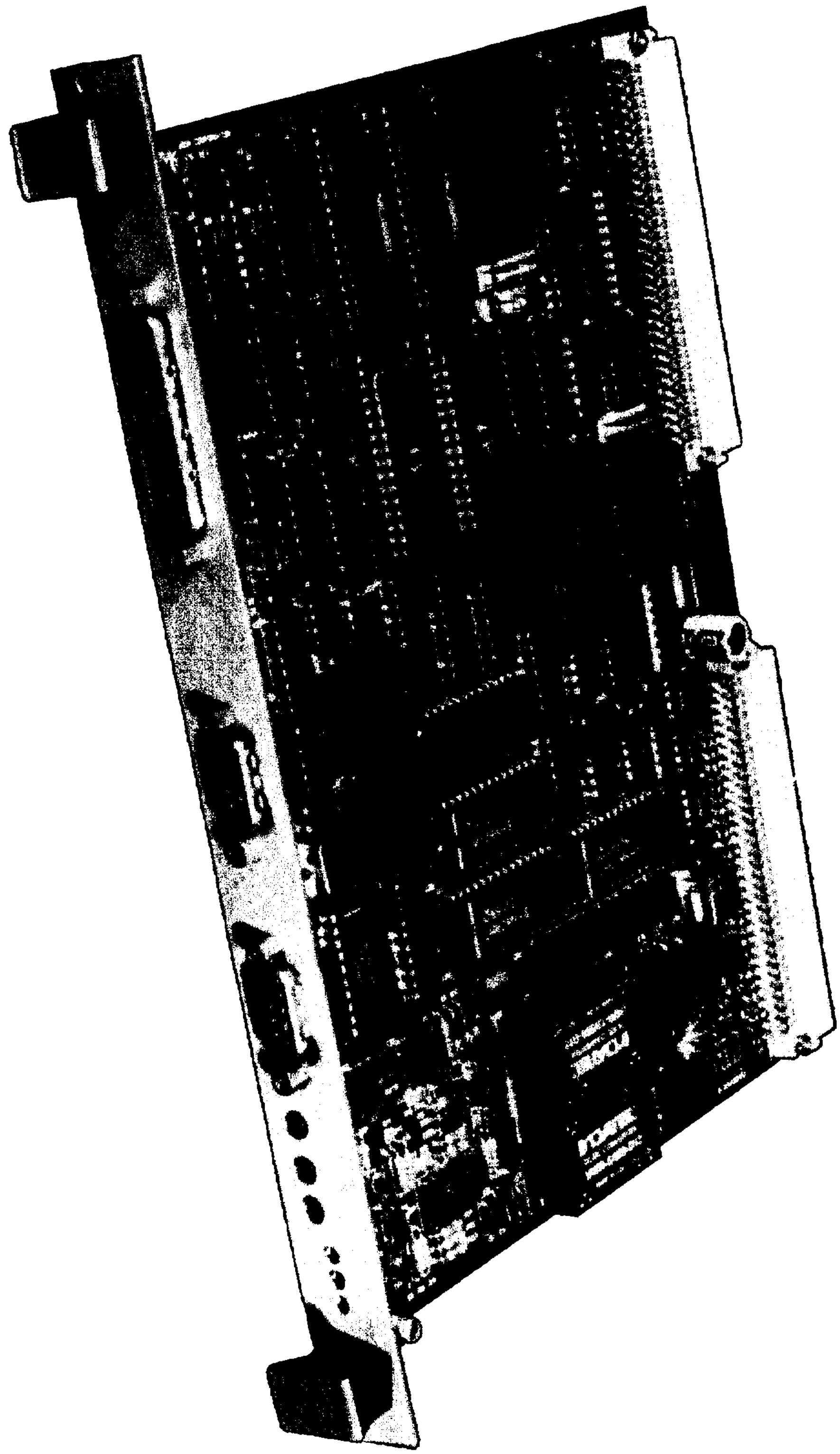

Figure 10. WIRE PILOT Controller Board layout

One VMEbus WIRE PILOT controller board was assembled to test the circuit board design. A software development tool running on a PC-AT was used to test the new VME bus WIRE PILOT controller board. The development tool requires a serial interface and a large amount of RAM located on the target board. Software written and compiled on the PC-AT is loaded into RAM via the serial interface and executed on the target hardware platform under the control of the software development tool. This allowed quick development of software routines to exercise and test the VME bus controller board hardware. Hardware functions were tested in a logical order, beginning with the CPU, memory and one serial interface. With this hardware functioning correctly, the rest of the hardware testing proceeded from one functional block to the next until everything but the VME bus interface was tested. This board was integrated into a stand-alone system enclosure with two power supplies and a three axis motor amplifier. The system was cabled to provide the interface connections to the MWG, operator's terminal and the software development system. This system was used to complete the development, integration and test of the WIRE PILOT operational software.

The second PC board was assembled and operationally verified in the stand-alone enclosure. The board was removed from the stand-alone system and installed in a VME bus computer system consisting of a Heurikon CPU board running the OS9 operating system in a three-slot VME bus backplane. Software programs were developed on the VME bus computer system to control the WIRE PILOT operation VIA the board's VME bus interface and interrupt control interface. With the VME bus controller board installed in the VME bus computer system, the other components of the WIRE PILOT were attached via interface cables. Operation of the WIRE PILOT system via the VME bus backplane was tested, including interrupts.

Documentation for the WIRE PILOT system is provided under this contract. This includes the "NRC - Wire Pilot User Manual".

3.3 PHASE III SYSTEM INTEGRATION

System integration of the Automated Wire Delivery System was performed on the vertical tool in building 4705 at Marshall Space Flight Center. Lockheed Martin personnel under with the guidance of NRC installed the hardware into the weld control cabinet of the vertical tool. The hardware components installed into the weld cabinet were: Technology 80 model 6409 3-axes servo motor amplifier; Power One 15V 4.5A linear power supply; a DIN rail mounted ribbon cable/screw terminal strip breakout module; rear cabinet pendant interface bulkhead connector; motorized wire guide interface cable bulkhead connector; RC filter assembly on encoder input signal lines; system interconnect wiring and cabling and VMEbus AWDS control module.

The motorized wire guide interface cable was routed from the weld controller rear door to the torch. The pendant interface cable was routed from the weld controller rear door to the Wire Pilot pendant located next to the weld control pendant. A mounting bracket was fabricated to attach the welding torch and cross-slide mechanisms to the motorized wire guide. The mounting bracket assembly was attached to the fiberglass rod of the automatic voltage control cross slides. The system was tested "See section 4.1.8".

Additional integration into the weld control system will require modification to the weld controller software. Lockheed martin personnel have written a simple routine to read the Wire Positioner status information through the VMEbus and display it in an X-Window. The Wire Pilot status information was also recorded by the weld control system using its built data in recording features.

3.4 SOFTWARE DEVELOPMENT

The first version of the AWDS was used to develop methods of maintaining wire contact in order to prevent wire dripping. A wire contact sensor was developed.

The second version of the AWDS was used to develop a wire pressure sensor and three axis motion control based on three parallel shafts.

The third version of the AWDS is a refinement of the second version. Better wire pressure sensing electronics and improved motion control were developed. It provides a production ready user interface pendant and a VME bus computer interface.

The structure of the software is completely different in the third version of the AWDS as compared with the two previous experimental versions. In the production version a real-time kernel is used to provide a prioritized preemptive multitasking environment. The various tasks communicate primarily via messages. Tasks are dedicated to performing the following functions: Motor update; motion control; pendant user interface; VME bus user interface; analog sensor input; and joystick input. The motor update task is driven by a 100 Hz timer. All other tasks are driven by message events from the motor update task at 20 Hz or by other asynchronous events such as keypad input. The motion control task is responsible for the automatic mode that maintains the wire contact pressure. The WIRE PILOT software is composed of approximately 11000 lines of C language source code.

The first and second versions of software for the AWDS was developed on a STD bus based computer containing an 80188 microprocessor. This machine was assembled from COTS components. Halfway into the third and final production version, the system was ported to the newly built custom VME bus printed circuit board containing an 80C186 microprocessor and an 80C187 math coprocessor.

A complete description of the operation and control software for the Wire Pilot is found in the "NRC - "Wire Pilot User Manual".

3.5 *OPERATIONAL SPECIFICATIONS OF THE WIRE PILOT*

3.5.1 Wire Pilot Controller

Controller: 6U VME; A16-08; interrupter; P1 and P2 connectors
Processor: 80C186-12 high integration CMOS processor
80C187 math coprocessor for performing coordinated motion.
Pressure control: 16-bit bridge transducer A/D converter interfaces to the MWG wire pressure load cell.
Motor control: Pulse width modulation control of the MWG motors using three National LM629 precision motor controllers.
Memory: 64 Kbytes EPROM; 128 Kbytes SRAM;
4 Mbits of serial EEROM are maintaining 4 different operational configurations.
Serial interface: Intel 82510 asynchronous serial controller, RS-422 provides interface to operator's terminal.
Wire contact sensor: Circuit detects when the wire is in contact with the work and also when the wire is dripping.
Digital I/O: 8 digital inputs; 4 digital outputs; optically isolated E-Stop input; optically isolated E-Stop output. (Provides a joystick interface, or connection with any switch-based operator's pendant.)
Power requirements: +5 VDC @ 2 A Typical (2.5 A Max.); +12 VDC @ 600 mA
Operating temperature: 0 to 70 degrees C
VME Bus interface: 4 Mbytes dual port ram interface Interrupts to host processor
Table top or 19" rack mount enclosure
Box dimensions: Height: 6 13/16" Width: 16 5/8" Depth: 13 7/8"
Available with or without 19" rack mounting brackets.
3-axis motor amplifier
Technology 80 - Model 6409 3-axis servo-motor amplifier
Operating temperature range: 0 to 70 degrees C
Motor drive voltage: 12 to 48 VDC
Motor peak current: Switch selectable from 0.00 to 3.00 Amps
Logic voltage: +5 VDC @ 180 mA
Power supply: (Motor) +15 VDC @ 3 Amps
Power supply: (Controller) VDC @ 1.25 A
Interface connections:

Operator's terminal	D-Sub 9, male
Joystick control	D-Sub 25, male
Motorized wire guide	D-Sub 37, female
Wire connection to work	binding post

3.5.2 Motorized Wire Guide

Housing:

Height: 3" Width: 2 1/8" Depth: 8 3/8" Weight: 4 lbs.
Head extends out 4 1/8" at the home position

Position control:

Three linear drives control three axes of motion; X-axis (left/right), Y-axis (in/out), Z-axis (wire angle)

Linear drive mechanism:

Lead screw provides two inches of linear motion without rotation of the external drive shaft.

3 parallel linear drives provide coordinated motion:

X-axis (wire left/right):	0.0+/-0.20 inches of motion
	0.00 - 0.20 inches/second
Y-axis (wire in/out):	2 inches of motion
	0.00 - 0.50 inches/second
Z-axis (wire entry angle):	10 to 35 degrees
	0.0 - 5.50 degrees/second
	1.0

Patented wire guide tip mechanism measures wire pressure.

Linear positioning accuracy and repeatability:

Encoder feedback on motors provides accurate positioning of the wire guide tip, with 0.003" accuracy and repeatability.

Production-hardened construction:

All aluminum motor housing
Stainless steel lead screw and drive shaft
Aluminum wire guide tip head
12 MM motors with bellows coupler for isolation
LEMO quick connect/disconnect connectors
50 lb. load cell
Crash protection in head and motor housing:
Head attached with heavy-duty spring coupler
spring loaded linear slide in housing mount
Accommodates industry standard wire guide tips
Easy attachment of wire liner using compressed gas fittings
Internal Teflon tip liner prevents wire galling

3.5.3 Operator's Terminal

Customized Q-Term II Model T480

Power requirements:

5.5 to 24 VDC unregulated (Regulated current consumption: 5 VDC @ 80 mA)

Operating temperature:

-10 to +60 degrees C

Weight:

10.5 Oz

Serial interface:

RS-422, D-Sub 9, female

Display:

3-row x 20-column backlit LCD display

Keypad:

24-key keypad

Indicators:

4 LED indicators on keypad

Software:

Configured to operate with the WIRE PILOT Controller

3.5.4 Operating Modes

Idle mode:

Idle mode is the system power-up mode. Configuration or Manual mode can be initiated from here.

Configuration mode:

Configuration mode allows the operator to modify the behavior of the WIRE PILOT system. There are four separate configurations that may be selected, modified and saved.

Manual mode:

Manual mode allows the operator to manually position the wire using the operator's terminal or an optional joystick/pendant control. The operator can control all three axes. Wire angle is coordinated with the in/out motion to move at a constant angular rate, moving about the position where the wire is programmed to contact the work (wire guide to torch centerline distance). X-axis (left/right), motion is coordinated with the Y-axis (in/out), to provide linear motion at the end of the wire instead of an arc or curved motion.

Automatic Mode:

In Auto mode, the WIRE PILOT controller autonomously controls the MWG in/out motion as a function of wire pressure to maintain the programmed wire pressure set point. The operator controls the left/right and the wire angle using the operator's terminal or optional joystick control.

SECTION 4. RESULTS AND CONCLUSIONS

The Phase III research study resulted in the delivery of the WIRE PILOT system. The stand-alone system consists of a 19 inch rack mountable controller, a small hand-held operator's terminal with cable and the redesigned three axis MWG with cable. The control cabinet contains the single board VME bus controller, a three axis motor driver, power supplies and cabling. A WIRE PILOT VME bus controller board is provided for installation into the Marshall Automated Weld System Advanced Weld Controller (MAWSAWC). Documentation is provided to interface the MAWSAWC to the WIRE PILOT VME bus interface. Manufacturing documentation is provided, consisting of a user's manual, schematics for the VME bus controller board, mechanical drawings for the MWG and source code for the WIRE PILOT software.

The Phase III MWG incorporates a new drive strategy that provides increased strength and accuracy, encloses the MWG drive mechanism, provides quick disconnects for the Wire Pressure Sensor Tip and the rear mounted Interface Cable. In addition a head-on crash protection system has been implemented to prevent damage to the MWG in case the unit is rammed into the work. The wire guide tip was redesigned to be much smaller, more rigid and able to withstand higher temperatures than the prototype. The WIRE PILOT controller board is a 6U high VME bus A16-D08 slave and an interrupter. The operator controls the WIRE PILOT using the operator's terminal, a joystick, a pendant or the VME bus interface. The board contains a microprocessor and a math coprocessor which control three pulse width modulation DC motor controller chips, an RS-232 serial interface, a wire contact sensor interface, a wire pressure sensor interface, an RS422 serial interface, a VME bus shared memory interface and a serial EEROM (Electrically Erasable Read Only Memory) in which the WIRE PILOT configuration is stored.

4.1 SYSTEM TESTING

4.1.1 Test Plan

A test plan was created for testing the Production Ready AWDS as specified in this development contract. Twenty-three tests were performed during a three-week period. The tests were performed at NASA/MSFC. The WIRE PILOT was tested with 0.063" aluminum wire, 0.093" aluminum wire and 0.045" stainless steel wire. Welding was performed using the VPPAW process when using the Aluminum wire and the GTAW process when using the stainless steel wire. The WIRE PILOT tests contained variations in the tool travel rate, wire feed speed and arc voltage with the different wires and processes. Operation of the WIRE PILOT was observed and test data was recorded. The WIRE PILOT and welding equipment was instrumented to record with a data acquisition system to record the parameters listed in table 5.

Table 5. WIRE PILOT WELD TEST PARAMETERS

1	WELD CURRENT
2	WELD VOLTAGE
3	TRAVEL RATE
4	WIRE PRESSURE (LOAD CELL)
5	WIRE FEED SPEED
6	TORCH STAND-OFF
7	MWG POSITION
8	WIRE DRIPPING

NOTE: OTHER PARAMETERS WERE RECORDED ON THE COMPUTER PRINTOUTS OF THE WELDS.

4.1.2 Vertical Up VPPAW

Seven tests were performed for 0.063" diameter aluminum wire. The seven tests were repeated using 0.093" diameter aluminum wire. All welding tests were vertical up using aluminum wire and 0.25" thick aluminum plates. All weld tests were root passes with a drilled keyhole at the start location. The last test square butt-welded two plates. The tack welds were left on the plates for the AVC to go over. The tests are listed in table 6.

Table 6. Test Descriptions for WIRE PILOT

Test WP02	No Weld, drag 0.063" diameter wire along flat plate.
Test WP03	No Weld, feed 0.063" diameter wire and drag along flat plate.
Test WP04	AVC weld on a flat plate with no parameter changes and using 0.063" diameter wire.
Test WP05	AVC weld on a flat plate with programmed AVC changes and using 0.063" diameter wire.
Test WP06	AVC weld on a flat plate with WIRE PILOT commanded wire angle changes and using 0.063" diameter wire.
Test WP07	AVC welds on a flat plate with programmed wire feed speed changes and using 0.063" diameter wire.
Test WP08	AVC weld on a bent plate that starts flat, inclines up, runs flat, inclines down and again runs flat, with no parameter changes and using 0.063" diameter wire.
Test WP09	No Weld, drag 0.093" diameter wire along flat plate.
Test WP10	No Weld, feed 0.093" diameter wire and drag along flat plate.
Test WP11	AVC weld on a flat plate with no parameter changes and using 0.093" diameter wire.
Test WP12	AVC weld on a flat plate with programmed AVC changes and using 0.093" diameter wire.
Test WP13	AVC weld on a flat plate with WIRE PILOT commanded wire angle changes and using 0.093" diameter wire.
Test WP14	AVC weld on a flat plate, with programmed wire feed speed changes, using 0.093" diameter wire.
Test WP15	AVC weld on a bent plate that starts flat, inclines up, runs flat, inclines down and again runs flat with no parameter changes and using 0.093" diameter wire.
Test WP16	Perform a nominal square butt weld with AVC changes. This is a weld of two plates, not a bead-on-plate.

Test data was recorded for the actual welds. Operationally, the WIRE PILOT system maintained the wire positioned against the work during all welds. There were no observable effects on the wire pressure control due to increased or decreased wire feed speed or travel speed. During AVC motion, the WIRE PILOT maintained the pressure within +/- 6 ounces of the pressure set point of 8 ounces. The pressure set point of 8 ounces was determined through trial-and-error to be the minimum pressure set point which provided good response to AVC changes Other parameters of the WIRE PILOT pressure control algorithm are the P, I and D settings. The WIRE PILOT worked best when P=12, I=0 and D=6. These configuration values worked for all wires of all sizes. Another critical parameter for the correct operation of the system was the correct wire stick-out. This needed to be between 1.5" and 1" depending on how hard or soft the wire was. Another observation was with smaller wire size, a larger wire feed angle was required (due to increased bending of the wire). 0.093" wire could be fed at 12 degrees where the 0.043" wire had to be fed at a minimum or 18 degrees to keep the copper wire tip from ever touching the plate. The square butt welds were radiographically inspected. No internal defects were noted.

4.1.3 Pressure Feedback ASOC Testing

With the operation of the WIRE PILOT system tested, an Automatic Standoff Control (ASOC) concept was tested using the wire pressure as the feedback to the AVC controller. The wire pressure sensor feedback signal was amplified and conditioned to provide a decrease in voltage with an increase in wire pressure. The signal conditioning circuitry provided 21 volts at the optimum wire pressure of eight ounces. The AVC was commanded to maintain its input voltage at 21 volts. The AVC moved both the torch and the MWG to maintain a 21-volt set point, thereby controlling the wire pressure at 8 ounces. Torch height was controlled by moving the MWG in toward the plate or away from the work, causing an increase or decrease in the wire pressure. The AVC system moved the torch in the opposite direction an equal but opposite distance to maintain the pressure set point programmed into the AVC.

The welds performed to test the ASOC concept using wire pressure feedback are described in table 7. This set of tests did indeed verify the ASOC concept, showing that the WIRE PILOT system with additional circuitry to feedback wire pressure into the AVC system is capable of controlling torch standoff. ASOC control performed as well as AVC with some positive operational side effects at the start and end of the welds, as well as when rapid parameter changes were made. All tests were vertical up using the VPPAW process on 0.25" thick 22190T87 aluminum.

Table 7. Test Descriptions for WIRE PILOT ASOC Tests

Test WP17	ASOC weld on flat plate, no parameter changes, using 0.093" diameter wire.
Test WP18	ASOC weld on flat plate, with programmed standoff changes using 0.093" diameter wire.
Test WP19	ASOC weld on flat plate, with programmed wire angle and wire speed changes using 0.093" diameter wire.
Test WP20	ASOC weld on bent plate that starts flat, then inclines up, then runs flat, then inclines down and again runs flat. No parameter changes using 0.093" diameter wire and vertical travel.
Test WP21	ASOC autogenous weld on flat plate, dragging wire for stand off sensing.
Test WP22	Perform a nominal square butt weld with ASOC changes. This is a weld of two plates, not a bead-on-plate.

With a pre-load on the wire pressure above the pressure set point, as soon as an arc is established the AVC head can be unlocked and the AVC will move the torch out from the plate. At the end of the weld, the wire can be slowly retracted, causing the AVC to move the torch in toward the work. The start of the weld and the end of the weld are times when AVC can react erratically. AVC also reacts to changes in parameters other than voltage, particularly arc current (ref [11]) and plasma gas flow rate. The square butt weld was radiographically inspected. No internal defects were noted.

4.1.4 Horizontal GTAW

Further testing of the WIRE PILOT was conducted using stainless steel wire and welding on an Inconel plate using the GTAW process. The first tests consisted of wire pressure control with AVC changes while horizontal welding a bead on a plate. The second tests consisted of wire pressure ASOC control with different standoffs. Another test using ASOC welded over two horizontal beads simulating large tack welds. The WIRE PILOT system operated successfully in maintaining the wire in contact with the plate with the 0.045" diameter stainless steel wire. The smaller diameter wire required one inch of stick-out for accurate placement of the weld wire in the weld pool. The WIRE PILOT parameters used were 8 ounces of wire pressure, P=12, I=0 and D=6. A video was made of the WIRE PILOT in operation during both VPPAW vertical up welding of aluminum and GTAW horizontal welding of Inconel. The video was made by Rocketdyne employees working at MSFC who requested the WIRE PILOT tests using the 0.043" diameter stainless steel wire. They showed the video to Rocketdyne employees in Caroga Park, California.

4.1.5 Temperature Testing

Temperature testing was performed to ensure the MWG tip does not overheat. A weld schedule was created to provide a weld current of 300 Amps with no tool motion and no wire feed. A water-cooled copper fixture was installed as the work for this test. The MWG was positioned at an angle of 11.88 degrees to place it as close as possible to the plasma arc with the wire initially extended to within 3/8 inches of the plasma arc near the top of the torch cup. Thermocouples measured temperature at four locations on the wire guide tip, T1, T4, T5 and T6 (see figure 11). T1 was located at the top of the wire guide tip where the wire liner is attached. A Nylon washer provides isolation of the inner liner from the pressure sensor tip of the MWG. T4 was located near the pressure sensor setscrew. T5 was attached to the copper extension and T6 was attached to the copper wire guide tip. The inlet and outlet water temperature for the water-cooled copper fixture was measured. Temperatures were measured every minute for the first 5 minutes, every two minutes for the next ten minutes and every 5 minutes thereafter. The test ran for approximately 90 minutes at which time the copper torch orifice melted and shorted to the work.

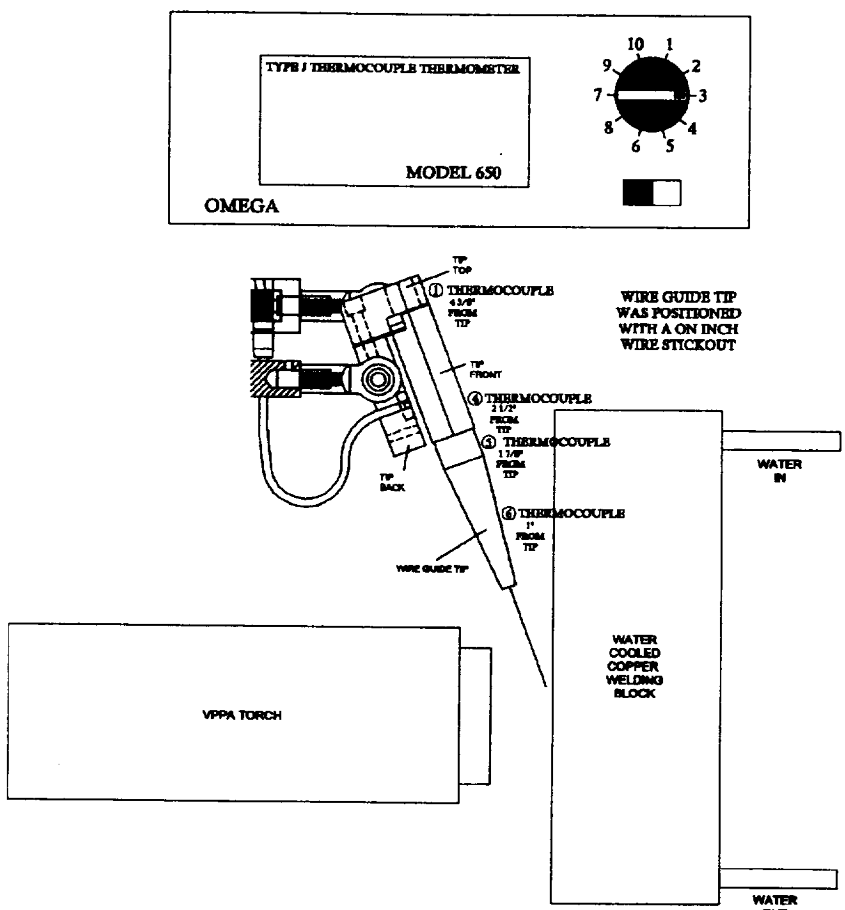

Figure 11. Wire Guide Tip Temperature Test Instrumentation

Test results indicate the wire guide tip operated within temperature specifications of the pressure sensor and wire guide tip material specifications for the TEFLON liner and nylon washer. The temperature data is shown in table 8. A graph of this data is shown in figure 12. After the first 20 minutes of the test, the wire was extended to within 1/4 inch of the plasma arc at the edge of the hole in the copper fixture to simulate a worst case scenario. Normally the wire is being fed and should not carry the heat as quickly back to the wire guide tip. The pressure sensor has an operating temperature range from -65 degrees Fahrenheit to +250 degrees Fahrenheit. Nylon has a melting point above 400 degrees Fahrenheit and TEFLON has a melting point above 600 degrees Fahrenheit. The wire pilot tip was disassembled to see of any changes could be observed in the tip components. No changes were observed.

Table 8. Temperature Testing - Wire Guide Tip Test Data

TIME (minutes)	T1 °F	T4 °F	T5 °F	T6 °F	W Temp In °F	W Temp Out °F
1	77	81	81	83	78	86
2	78	82	84	84	78	86
3	79	84	85	85	78	86
4	80	84	85	86	78	86
5	80	85	86	87	78	86
7	81	87	87	89	78	86
9	82	87	88	90	78	86
11	83	89	90	91	78	86
13	84	90	92	93	78	86
15	85	93	95	97	78	86
20	87	96	97	99	78	86
25	91	112	115	119	78	86
30	95	124	129	134	78	86
35	101	131	136	141	78	86
40	103	134	139	145	78	86
45	106	139	145	150	78	86
50	109	143	149	154	78	86
55	110	144	150	156	78	86
60	111	145	151	156	78	86
65	112	147	153	159	78	86
70	112	144	150	155	78	86
75	111	143	149	155	78	86
80	112	145	151	156	78	86
85	115	149	155	160	78	86

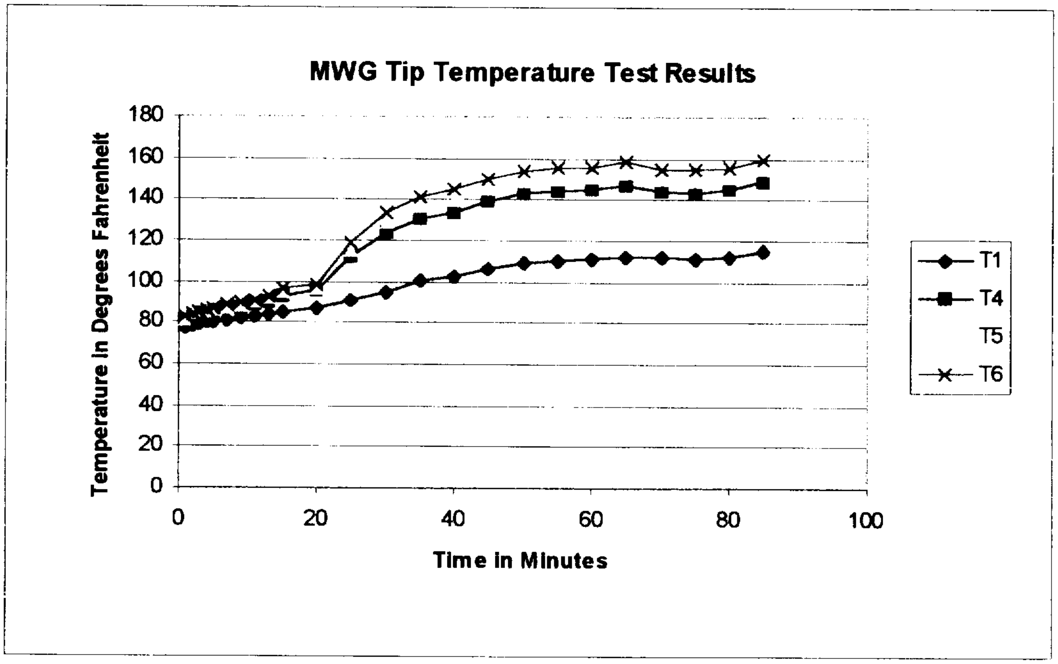

Figure 12. Graph of Temperature Test Date

4.1.6 VME Bus Interface Testing

The VME bus interface testing was performed using a three slot VME bus chassis with a monolithic P1 and P2 backplane. The CPU was a 68040 based Heurikon CPU board running the OS9 operating system. Software was written to exercise the VME bus interface and to generate commands to and report real-time status from the WIRE PILOT controller board. The test software provides a menu of commands which are available to the VME bus control system operator and provides real time status of the WIRE PILOT MWG position, wire pressure and command response status. The WIRE PILOT system performed all operations from the VME bus interface.

4.1.7 Homing Position Accuracy Test

The homing accuracy test was performed in the laboratory on the bench with the MWG clamped to a table with a dial indicator mounted to measure the movement of the MWG tip. The MWG home positioning error was measured as less than one thousandth of an inch when moving in the same direction and +/- 2.5 thousandths when home position was approached from opposite directions, Thus exceeding the homing accuracy requirements of +/- 0.010".

4.1.8 Integration Testing On the Vertical Tool

System integration of the Automated Wire Delivery System was performed on the vertical tool in building 4705 at Marshall Space Flight Center. Lockheed Martin personnel under with the guidance of NRC installed the hardware into the weld control cabinet of the vertical tool. The hardware components installed into the weld cabinet were: Technology 80 model 6409 3-axes servo motor amplifier; Power One 15V 4.5A linear power supply; a DIN rail mounted ribbon cable/screw terminal strip breakout module; rear cabinet pendant interface bulkhead connector; motorized wire guide interface cable bulkhead connector; RC filter assembly on encoder input signal lines; system interconnect wiring and cabling and VMEbus AWDS control module.

The motorized wire guide interface cable was routed from the weld controller rear door to the torch. The pendant interface cable was routed from the weld controller rear door to the Wire Pilot pendant located next to the weld control pendant. A mounting bracket was fabricated to attach the welding torch and cross-slide mechanisms to the motorized wire guide. The mounting bracket assembly was attached to the fiberglass rod of the automatic voltage control cross slides.

In the testing of the newly installed equipment, the Motorized Wire Guide was observed to move (not desired in the production system) when the welding system was powered on. This behavior did not occur when powering on the standalone system and was not anticipated to be a possible system problem. The solution was the installation of a 5-second delay relay in the weld control cabinet. The relay delayed the application of +15V motor voltage to the 3-axes servo motor amplifier. The weld control system power sequencing was allowing the motor amplifier to move the MWG motors while the weld controller installed in the VME bus was initializing. The relay resolved the power-on movement problem.

A second problem was observed with the operation of the motorized wire guide when attached to the weld control cabinet. When commanded to move by the pendant, the motorized wire guide would periodically stop. An error message would be displayed indicating the MWG needed to be "homed". The operation of the MWG steadily worsened. The encoder feedback signals were found to be much noisier in the weld cabinet integrated wire positioning control system than in the standalone control system. Voltage spikes of approximately 4 volts P-to-P where observed during both the high and low encoder signal times. The noise was causing excessive error in the motor position feedback signal. The encoder feedback signals input to the TI SN75175 "quadruple differential line receiver chip" operating on +5v with a +3V comparator threshold. The motor encoders were also operating on a +5V supply from the VME bus controller board. The motor encoders can be operated with up to a +15V supply. The receiver chip has a -12V to +12V common mode input voltage range. The supply voltage to the motor encoders from the VMEbus AWDS controller was changed from +5V to +12V. This moved the noise out of range for the comparator voltage of the receiver chip.

With this modification in place, the system was reconnected. Again the MWG was getting position errors, shutting off the motors. This time the problem was narrowed down to the MWG interface cable. Both of the interface cables to the Wire Pilot pendant and motorized wire guide are in excess of 100 feet. The cable shielding at the MWG LEMO connector was loose. The shield wiring was repaired. After reattaching the repaired cable, the MWG operated correctly.

Additional integration into the weld control system will require modification to the weld controller software. Lockheed martin personnel have written a simple routine to read the Wire Positioner status information through the VMEbus and display it in an X-Window. The Wire Pilot status information was also recorded by the weld control system using its built data in recording features.

SECTION 5. RECOMMENDATIONS AND APPLICATIONS

With a look toward the future and the further advancement of welding, here are the recommendations and potential application for the WIRE PILOT system.

5.1 RECOMMENDATIONS FOR FURTHER DEVELOPMENT

NRC recommends further research into the use of wire pressure ASOC in place of or in conjunction with normal AVC control in an Advanced Weld Control System. NRC also recommends the final step of integrating the WIRE PILOT into the new Advanced Weld Control Systems be made.

5.2 POTENTIAL APPLICATIONS FOR THE WIRE PILOT

Potential applications for the WIRE PILOT are discussed in this section.

5.2.1 Automatic Stand-Off Control (ASOC) (GTAW; VPPAW; etc.)

Another mode of operation for the WIRE PILOT is for automatic standoff control wherein the output from the wire pressure sensor is used to generate a voltage that is maintained by the AVC controller/motor. Wire pressure above the set point value causes the AVC controller/motor to increase standoff to reduce the wire pressure, and vice-versa. This provides for a constant standoff, as the torch will stay a constant distance above the point where the wire is in constant pressure contact with the work piece. Driving the MWG in/out, to which the AVC controller/motor will respond, does standoff changes. Specific conditions in which ASOC presents advantages over AVC: sudden changes in arc length, such as when the head is locked at the start of a weld and then unlocked: AVC tends to overshoot; the start of the weld where the wire begins to feed in: with ASOC the stand-off will increase smoothly to the preset stand-off, while AVC dives or jumps; at weld terminations when you want to ramp down the stand-off while decreasing the current: unlike AVC, ASOC de-couples stand-off from weld current so each can be ramped independently; ASOC uses actual units of distance, rather than trying to equate an arc voltage to a stand-off distance; machine-to-machine variations in voltage for a given stand-off are common: this problem would not exist with ASOC.

5.2.2 Robotic Welding (GTAW; PAW)

Closed-loop control of wire contact and centering will be possible through the robot controller (if VME based). If closed-loop adaptive control of wire feed speed (adaptive fill) is used, the user may want to direct wire into different parts of the weld pool under different filling situations (for example: to improve side wall fusion for example). A dry run preview of the path to teach and adjust the path according to the force sensor output. The height of irregularities (like at tack welds) could also be measured during a pre-weld inspection. Weld bead height could be measured between passes and when the weld is complete.

5.2.3 Dry Runs (ANY PROCESS)

AVC mode

Dry runs can be made by dragging filler wire at the location where it will be entering the weld pool to see how the MWG will respond.

ASOC mode

Dry runs can be made by dragging filler wire at the location where it will be entering the weld pool to see how the AVC drive motor will respond.

5.2.4 Transfer Between Machines / Set-Ups

ASOC mode

With AVC, when changing weld power supplies, and/or fixtures and cabling, different AVC voltage settings are often required to attain the same stand-off since the power supply characteristics and the resistance of the AVC circuit change. With ASOC this problem would go away because ASOC is independent of the arc.

Using ASOC to set AVC

When it is preferred to use AVC for a weld, ASOC could be used during the start up and first few seconds of the weld to provide an opportunity to measure what the individual system's voltage is at the desired preset standoff, and then automatically switch to AVC using the measured voltage as the AVC set point. Any time there is a transition or change in weld parameters or conditions, a short duration switch to ASOC could be done to adjust standoff and the corresponding AVC set point value. Even on a long static condition weld, it might be desirable to have a short duration switch to ASOC at regular intervals to tune-up the standoff distance and the AVC set point.

5.2.5 Low Frequency Pulsing (Like P-GTAW)

ASOC mode

With pulsing (usually less than 10 Hz) the arc current fluctuates between a high and a low value, therefor the arc voltage also fluctuates, which will cause AVC to react by raising and lowering stand-off (the 'sewing machine' effect). When using AVC this is dealt with by using an average voltage, a large dead-band, or circuitry to sample only the high pulse voltage. With ASOC, the pulsing would have no effect on the standoff.

5.2.6 Magnetic Arc Oscillator

Either mode

When using a magnetic arc oscillator, the arc and pool oscillate back and forth, but the torch does not. With a fixed wire feed position, the pool can actually be oscillated out from under the wire, causing it to misfeed. With WIRE PILOT, it would be possible for the side-to-side motion of the wire to be programmed to correspond to the oscillations of the magnetic field, the arc and weld pool.

5.2.7 Low Current Welds (GTAW; Needle Plasma)

ASOC Mode

Low current welds use low voltages which are harder to maintain with AVC. At low voltages using AVC, standoff becomes more sensitive to voltage changes. ASOC will control standoff independent of current/voltage, even if both are zero (i.e. a dry run).

5.2.8 Short Stand-Off Welds (VPPAW)

ASOC mode

If using a very short stand-off and approaching a tack weld, with AVC the filler wire could be pinched between the shield gas cup and the tack weld before AVC responds to the tack weld rise. With ASOC, the torch raises at the moment the wire starts raising, preventing pinching.

5.2.9 Narrow Groove Welding (GTAW)

AVC Mode

With relatively long wire stick-outs sometimes used, this would prevent erratic filler wire cast from causing the wire to drip or touch the electrode. The groove sidewalls would limit the cast's side-to-side effect.

ASOC Mode

If there's a momentary arcing to the sidewall, with AVC there will be a reaction (either diving into the part or climbing the wall). With ASOC there is no reaction, giving the arc a chance to return to the joint and giving the operator a chance to correct the problem. Rather than using a long wire stick-out (especially with soft wire and/or erratic wire cast) it may be necessary to use an extended wire guide tip to minimize stick-out.

5.2.10 Torch Weaving

ASOC mode

When weaving the torch in a groove, the AVC reacts to changes in arc length as the groove edges are approached. In cases where this is undesirable, ASOC would correct it. When weaving on a flat plate, the AVC may cause standoff changes at the extremes of the weave - again, if this were undesirable ASOC would correct it.

5.2.11 Weaving Opposite Torch Weave To Improve Side Wall Fusion (GTAW)

Either mode

When welding in a u-groove on a material that is difficult to get good side wall fusion, it could be beneficial to weave the wire relative to the torch to keep the wire entry point near the edge of the pool away from the side wall. This keeps the wire from cooling the pool where it is fusing into the sidewall, thereby helping prevent lack of fusion defects.

5.2.12 Avoiding Filler Wire Sticking In Front Of Weld Pool

Either mode

When welding some materials (such as titanium) if there is too much pressure between the filler wire and the work piece the wire will stick to the work piece before entering the weld pool, causing wire feed problems. By maintaining a constant, but not too high, wire pressure, this problem can be eliminated.

5.2.13 Systems With Less Than Three Axes

Either mode

There will be applications where 3 axes are not needed. Fewer axes may be necessary to reduce the size to be able to fit into tight spaces. The axis most likely to not be needed is the wire angle axis, since this can be manually set and in many, if not most, applications it is not changed during a weld. Cross seam (side-to-side) adjustments are common, but this is often to correct for wire feed problems; with a good wire feeder and straight wire this axis would be next to go (some applications can also tolerate some side-to-side variation in wire feed position, such as when there is a very wide weld pool). If any customer or application required only one axis of motion, it would likely be the Y-axis (in/out).

5.2.14 Cutting (Plasma; Oxy-Fuel; Waterjet)

ASOC mode

These processes are sensitive to standoff variations. Using ASOC while dragging a wire or probe (maybe just the wire guide tip) would enable standoff to be controlled for these processes.

5.2.15 Electron Beam Welding

AVC N/A

These welds are made in a vacuum chamber, so remote operation is a necessity. Some design modifications of the MWG would be required to vacuum harden it. EB welds are often quite narrow so they are less forgiving of wire positioning errors (i.e. they would benefit from an accurate wire positioner like WIRE PILOT).

5.2.16 Laser Beam Welding

AVC N/A

These welds are often quite narrow so they are less forgiving of wire positioning errors (i.e. like EB welds, laser welds would benefit from an accurate wire positioner like WIRE PILOT).

5.2.17 Welding In A Chamber (Glove Box) Filled With Inert Gas

Either Mode

Remote automated operation is beneficial; there is a loss of dexterity with the gloves, and visibility is usually reduced because the operator is not as close to the work and is looking through a window of some sort.

5.2.18 Ultrasonic Inspection In Situ

Either mode

The wire feeder tip could be replaced with an ultrasonic inspection transducer(s). This would enable inspection in situ (without removing from tooling) using the same manipulator (a robot, for example) to traverse the same path, while keeping constant pressure on the transducer(s) to get more consistent readings.

5.2.19 Manual Welding (GTAW; PAW)

AVC mode

The torch handle could be hard mounted to the wire feeder, while a single axis motor drives the torch up or down relative to wire pressure. The welder could control arc length partly by feel then, instead of just by sight and sound. This could be useful in situations with limited visibility.

SECTION 6. BIBLIOGRAPHY

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